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Relationships linking preharvest mineral nutrition of 'McIntosh' apple leaf and fruit to storage disorders of fruit.

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Relationships Linking Preharvest Mineral Nutrition of 'McIntosh' Apple Leaf and Fruit to Storage Disorders of Fruit

A Thesis Presented

By

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Nutrition of 'McIntosh' Apple Leaf and Fruit
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INTRODUCTION

Apples are an important crop in the United States (U. S.). Over the past 8 years, the country has produced in excess of 150 million bushels of apples annually, of which Massachusetts has produced approximately 2 million bushels each year (31). McIntosh is the cultivar most widely grown in Massachusetts. Depression of the price of controlled atmosphere (CA) 'McIntosh' in years with fruit storage problems reflect lack of buyer confidence in quality. For example, in the 1969-70 and 1971-72 seasons there was a storage problem called 'soft McIntosh' which reduced fruit quality. The wholesale price of CA fruit dropped from $4.60 to $4.50 per bushel from the beginning to the end of the CA season in 1969-70 and rose from $5.10 to $5.25 per bushel in 1971-72. In contrast, the 1970-71 fruit quality was generally good, and CA 'McIntosh' prices rose from $4.75 per bushel at the beginning to $6.75 at the end of the season, a significant gain in price (46).

Apples are harvested in the U. S. from July through November. In order to supply consumers with apples throughout the year, some fruit must be stored for months before they are consumed. Unfortunately, the fruit often deteriorate in storage. The process of senescence may be slowed by conscientious maintenance of storage conditions and careful handling of fruit, but even under the best of conditions, some fruit emerge from storage in unmarketable condition. This is obviously not a desirable situation.

All fruit stored together do not come out of storage in the same condition. A number of factors affecting the condition of fruit after storage have been isolated. Faust and Shear (14) have summarized some of these factors. Mentioned among the factors influencing postharvest fruit quality are fruit size, crop size, pruning, rootstocks, maturity of apples at the time of harvest, storage of apples, water relations, and nutrition of fruit. The chief elements cited as influencing storage life of fruit were nitrogen (N), calcium (Ca), potassium (K), magnesium (Mg), phosphorous (P), and boron (B). Some of the disorders which negatively influenced fruit quality have been described by Smock (44). Among those disorders to which McIntosh fruit are susceptible are freezing injury breakdown, a number of chilling disorders, "McIntosh breakdown", senescent breakdown, and the CA-related disorders: brown heart, carbon dioxide-induced cavities, and low oxygen-breakdown. Fruit may also be infected by organisms causing decay, making fruit unmarketable. An additional storage disorder, scald, which mainly affects air-stored fruit, is described by Porritt, et al. (37).

Taking into consideration incidence of these fruit disorders and their undesirable effects, as well as factors which may influence disorder occurrence, a project was initiated in 1979 to provide information on the application of a rating system which would allow Massachusetts apple growers to determine, before harvest, the potential storage life of their fruit. Some of the methods used in designing this project were based on a system which is in commercial use in the United Kingdom (U. K.) (53). The project was set up to study the

relationships of Ca, Mg, K, P, and N to incidences of senescent breakdown, decay (rot), and scald of fruit after air or CA storage, and also to see if the minerals measured influenced fruit firmness, a critical quality factor for McIntosh, at harvest or following air or CA storage. The specific objective of the project was to develop multiple linear regression equations using Ca, Mg, K, P, and N concentrations in leaves and fruit of McIntosh trees to predict senescent breakdown, rot, scald, and firmness of fruit after air and CA storage.

C H A P T E R II

A REVIEW OF THE LITERATURE

Mineral nutrition has long been recognized as a significant factor governing post-harvest storage life of apple fruit. In 1936, DeLong reported that bitter pit in apple fruit was associated with low Ca concentration. Since then, effects of mineral nutrition on apple fruit, especially on postharvest condition of fruit, have been widely studied. A goal of most studies in this area has been to increase the understanding of what contributes to the quality of apple fruit both on the tree and after harvest, and to devise ways to obtain high quality fruit. High quality is defined by Huguet (21) as adherence to currently applied standards of color, size, and appearance of fruit. Storage disorders generally detract from the appearance of fruit.

To present a discussion of postharvest fruit disorders, it is necessary to have clear definitions of the disorders in question. Discussion here is mainly limited to senescent breakdown, storage scald, decay, and bitter pit/cork spot. Smock defines senescent breakdown (breakdown) as a softening, crumbling, and browning of cells, extending outward from the main vascular bundles (44). Storage scald (scald) is described by Porritt, et al. as a browning and sometimes roughening of the skin of the fruit which is often intensified after fruit have been removed from storage several days (37). The disorder is thought to be a result of oxidation reactions, hence is more commonly found on air-stored than on CA-stored fruit which have been kept under high O_2

tension (37). Bitter pits are small, brown, necrotic areas on the fruit surface, most often on the calyx end (37). Sometimes distinctions are made between bitter pit and cork spot, cork spots being described as larger and causing greater indentations into the fruit than bitter pit (14). Also, while bitter pit is generally restricted to the calyx end, cork spot can be found anywhere on the fruit. It is often difficult to separate the 2 disorders.

Low levels of leaf Ca have been associated with incidence of breakdown, rot, and bitter pit of stored apple fruit (10). However, it appears that postharvest fruit disorder occurrence is more closely related to low fruit Ca than to low leaf Ca (22,26,29,41,52). The literature consistently cites low fruit Ca concentrations as correlated to incidence of senescent breakdown (7,28,41,58,60), low temperature breakdown (28,60), decay (21,58), bitter pit (14,17,21,33), and scald (58). Low fruit Ca concentration has also been associated with increased rates of respiration in stored apples (3,15). Sharples (41) found Ca to be the only mineral consistently related to breakdown incidence. Others report that B may also help reduce breakdown of stored fruit (7), so that while Ca is generally regarded as the element with the strongest influence on postharvest fruit condition, at least B is also involved, probably because it is associated with Ca movement in plants (14). Faust and Shear (14) summarize contradictory reports on the effect of Mg in bitter pit development by stating that some research has shown that Mg induced bitter pit (25) while other research has suggested that Mg reduced bitter pit (33). Possibly the ratio Mg:Ca is

the critical factor in this relationship (41). Other reports state that high fruit Mg concentration reduced breakdown, although the small ranges in Mg concentration make a strong statement to that effect questionable (7,60). Perring found that high concentrations of Mg, K, and P were associated with reductions in low temperature breakdown (33). Fruit K in itself has not been associated with bitter pit incidence (42), but the ratio of K:Ca has been positively correlated to bitter pit (22,34,41) and susceptibility to Gloeosporium rot (41). High K concentration has also been positively correlated to scald incidence (56,58). In a laboratory experiment, when 800 umole of a saturated solution of KCl solution were injected into apple fruit, breakdown and bitter pit were sometimes increased (60). Other researchers were unable to find a correlation between fruit K concentration and fruit breakdown (58). Studies of the relationship between fruit P concentration and postharvest fruit condition have led to mixed results. Bramlage, et al. found no evidence that added P improves fruit quality, when P concentrations observed were relatively high (11), but significant relations between low fruit P concentration and breakdown were observed among commercial lots (7). Low temperature breakdown can be reduced by tree sprays of $Ca(H_2PO_4)_2$ and KH_2PO_4 (22). Others have found that low fruit P concentration was correlated positively to internal breakdown incidence (28,33). However, P concentration was not found by others to be correlated to breakdown (5,6). High leaf N levels (57) and high fruit N levels (6) have been associated with increases in a number of fruit disorders. High N concentration has been found in fruit affected

with bitter pit, and can exacerbate the effects of low Ca (14). High leaf N for McIntosh was also correlated with poor fruit color and soft fruit (57).

High concentrations of some minerals can depress levels of others in apple trees and fruit. High leaf N is related to low K concentration in apple leaf (42). This was also found in oats, tomato, and buckwheat when no limestone was added to the soil (12). Conversely, an increase in B can enhance Ca uptake by trees (42). Shear (42) also reported that Schmitz and Engel (1973. Erwerbobstbau. 15:9-14) found that sprays of zinc (Zn) and copper (Cu) increased Ca concentration of fruit and this decreased bitter pit. Experiments with apple trees grown in sand culture have demonstrated that decreased availability of Mg and K can increase Ca and N concentrations in the tree (29). This project also showed that decreased availability of Mg increased K uptake, but decreased availability of K decreased Mg uptake. Low K concentration in trees led to low P concentrations in fruit.

Non-mineral factors also have effects on fruit. Some of these effects may indirectly be mineral effects since some factors such as fruit size can affect mineral concentration. Large fruit have increased likelihood of developing bitter pit (14) and breakdown (27). Large fruit also are associated with low Ca (35) and high N (2) concentrations. Unfortunately, large fruit are also desirable (49). Water supply is critical for adequate Ca uptake by the tree (42,45). The growth regulators napthaleneacetic acid (NAA) and triiodobenzoic acid (TIBA) may affect translocation within the tree. TIBA increased

cork spot and decreased Ca in fruit peel (17). NAA when used in combination with $CaCl_2$ sprays reduced fruit breakdown more than $CaCl_2$ sprays alone (28). When used as fruit thinners, NAA and napthaleneacetamide (NAD) indirectly increase fruit size (45), which in turn affects Ca and N concentrations and occurrences of fruit disorders. Heavy pruning can also increase fruit disorders by increasing vegetative growth which results in decreased crop size and increased fruit size (14). Excessive terminal growth is associated with bitter pit, but the importance of maintaining adequate growth for the tree must be considered also (49). Summer pruning, as opposed to regular (winter) or renewal pruning, has been suggested as a way to reduce bitter pit (48). Rootstock choice may also have an effect on bitter pit incidence. Fruit from 'Northern Spy' seedling rootstocks were reported more susceptible to bitter pit than fruit from 2 dwarfing rootstocks (14). This may be an indirect effect of the relative vigor of the seedling rootstock. A last factor affecting storage disorders is fruit maturity at the time of harvest. Early harvest is reported to increase bitter pit development and late harvest to decrease bitter pit (14). Early harvest, though, has also been shown to decrease breakdown (27). In any case, it can be difficult to determine maturity of low Ca fruit, because chlorophyll is often lost early in fruit with low Ca concentrations (15). Fruit firmness is also a poor indicator of maturity of low Ca fruit, because these fruit may have abnormally high cellulose content which can affect firmness (15).

Mineral content of fruit can be altered in attempts to improve quality of fruit. This may be accomplished in a number of ways. As mentioned previously, mineral balance has an important role in determining fruit quality. Minerals may be applied to the soil, as foliar sprays, or as postharvest dips. A number of factors dictate the appropriateness of each of these methods.

Soil application of fertilizer is the primary source of added N, P, and K. Timing of applications may affect fruit quality. Studies have shown that early (summer) N application decreased fruit quality, while late (fall) application had no effect (52). Soil applications of Ca have not been shown to increase fruit Ca or improve fruit quality. Uptake of Ca by roots is very slow (24,43), and translocation within the plant is also slow (13). There are data indicating that NO_3^- stimulates Ca uptake (24,43) and that NH_4^+, K^+, Mg^{++}, and Al^{+++} depress Ca uptake (24). However, it is also reported that NH_4^+ increases movement of Ca into new leaves (43). Liming to a pH of 6.2 to 6.5 aids in Ca uptake (59). Increasing uptake of Ca and its movement into the fruit are desirable, but also it is important to maintain fruit Ca, which can move out of, as well as into, fruit (42).

Foliar sprays which place Ca directly into the fruit have been used effectively to increase fruit Ca concentration (27,34,59). These sprays have usually been as multiple applications of $CaCl_2$ (27,34) or $Ca(NO_3)_2$ (49) applied at intervals during July, August, and September. A single massive dose of $CaCl_2$ applied 2 days before harvest effectively raised Ca concentration, but caused damage to fruit (59). Foliar sprays of

kinetin, benzyladenine (BA), and B can increase Ca movement (13), which may increase Ca concentration in fruit. Where additional P has been desired, KH_2PO_4 and $Ca(H_2PO_4)_2$ sprays have increased fruit P concentration, but have also caused some injury to fruit (22).

Another approach to increasing Ca concentration in fruit has been the use of postharvest dips or drenches, usually in $CaCl_2$ solutions. Use of dips has been found to be effective, and has been recommended (1,34).

Having determined that mineral content is a critical factor affecting the quality of fruit, the question arises: What is the best way to assess the mineral status of the fruit? It is much easier to analyze apple leaves than fruit, so attempts have been made to correlate leaf mineral concentrations to fruit mineral concentrations. The correlations between leaf Ca concentration and fruit Ca concentration and breakdown incidence in Baldwin apples were found to be significant (10). However, more recent research has suggested that fruit analyses are preferable (8,32), because fruit analyses were shown to correlate better to fruit breakdown, rot, and scald than leaf analyses (e.g.58).

In searching for a method of fruit analysis, researchers have looked for a number of characteristics. An ideal method should be reliable, standardized, and reproducible (16,51). It must also detect similar concentrations of minerals from season to season (16). Most important is that the mineral concentrations, as measured, must reflect potential susceptibility to storage disorders, (51). It would also be useful to be able to perform analyses before regular fruit harvest dates so that

information gained from analyses may be put to use.

To determine when to sample, fruit factors as well as convenience must be considered. Mineral concentrations in fruit change through the growing season (4). One source reported that Mg and Ca concentrations dropped through the season, while K remained constant (20). Another found that Ca concentration dropped, while Mg remained fairly constant through the season (25). Different cultivars exhibited similar concentration patterns, but actual mineral levels were different among the cultivars (21). Caution should be observed when comparing even the same cultivars grown under widely varying conditions. Cox's Orange Pippin fruit grown in England contained the same Ca concentration as those grown in Australia and South Africa (35). However, P concentration was lower in fruit from New Zealand and Tasmania than in fruit grown in Japan and England (35). Fruit size affects mineral concentration, too, as mentioned earlier.

Decisions must be made concerning where, within the fruit, to sample. Some researchers have analyzed whole fruit, excluding seeds and stalks (32), thus avoiding this issue. A longitudinal gradient of mineral concentrations has been observed in fruit at maturity (25): Ca concentration was lowest at the calyx end and highest at the stem end of the fruit, while Mg concentration was lower at the stem end than the calyx end, and K concentration was constant throughout the fruit. In McIntosh, higher Ca concentrations have been measured on the red side of the fruit than on the green side (36). Webster, et al. found highly significant correlations between whole fruit and cortex Ca

concentrations (55). They found poor correlations between whole fruit and fruit peel Ca concentrations and between cortex sample and peel Ca concentrations.

When whole fruit have been sampled, analysis has generally been on a fresh weight basis and total mineral concentrations have been measured (32). A less bulky method than whole fruit analysis consists of taking opposite longitudinal sections of fruit (51). Others have used 7-cm diameter plugs removed from 1-cm thick equatorial slices of fruit (16,51). This method is easily reproducible. Weis, et al. (59) have sampled cortical strips just below the peel on the calyx end of the fruit. This method offered the advantage of analyzing the area of the fruit where disorders most often appear (59). Total mineral concentrations were measured on a dry weight basis. Himelrick (20) has measured minerals extracted using H_2O and $NaNO_3$. He considered H_2O- and $NaNO_3$- soluble minerals to be those which are physiologically active, and which therefore influence fruit characteristics. Himelrick (19) has also used an ion-sensitive electrode to measure Ca concentration in apple juice and found significant correlations between those measurements and total Ca in apple flesh.

Another sampling factor which has not been been precisely determined is number of fruit to be collected to gain a representative sample. Individual fruits vary greatly in mineral concentrations (e.g.36). Ferguson, et al. have used 20 fruit from each of 5 trees per block for a total of 100 fruit per block sampled. Turner, et al. (51) used opposite longitudinal sections from each of ten fruit as a sample.

Agricultural Development & Advisory Service (ADAS) in the U. K. suggests compositing 1 representative fruit from each of 25 trees per block sampled (30). The ADAS method has also been modified to use 7 cm diameter fruit instead of representative fruit (5,6,7,58).

A number of methods exist for interpreting results of mineral analyses. In New Zealand (16) and South Africa (49) threshold Ca levels, below which bitter pit problems may be expected, have been developed. Perring (33) has developed a similar system which incorporates fruit P as well as Ca concentrations. Ratkowsky (38) has advocated using correlation coefficients to relate mineral concentrations to fruit disorders; however, he has not explained how these might be used to make commercial recommendations. The system in commercial use in the U. K. (53) does not rely on statistical analyses, but rather on a ranking system which assigns risk factors based on a range of whole fruit Ca and N concentrations, as well as ratios of K:Ca, P:Ca, and Mg:Ca in the fruit. Also incorporated in the rating are factors relating fruit size, picking date, and tree age. Marmo (27) used multiple linear regression equations to predict breakdown in McIntosh fruit. Her prediction equations included fruit outer cortex concentrations of Ca, K, aluminum (Al), Zn, P, Cu, N, iron (Fe), manganese (Mn), and B, as well as factors of fruit size and maturity of fruit at harvest. These, and other researchers, have done a great deal of work defining the preharvest influences on the postharvest life of apple. However, clear definitions of storage risk based on mineral analyses have yet to be established.

C H A P T E R III

MATERIALS AND METHODS

In 1979 an experiment was established to study the feasibility of predicting fruit storage life based on preharvest mineral concentration of fruit.

That August, 34 blocks of McIntosh apple trees were selected in Middlesex, Worcester, Franklin, Hampshire, and Hampden counties in Massachusetts. A block of trees was defined as a group of trees of the same cultivar, McIntosh, grown in the same orchard under approximately the same conditions, i.e. soil type, water availability, air drainage, exposure, and management practices. From each block 25 representative trees were chosen for the experiment. During the third week in August one 7 cm diameter fruit was picked from the periphery of each of the selected trees. Fruit were composited by block resulting in 34 groups of 25 fruit each. Each group of fruit was subsampled for mineral analyses by each of 3 methods. Descriptions of these methods follow.

The calyx end of each fruit was peeled with a mechanical peeler (White Mountain Apple Peeler, White Mountain Freezer Co., Inc., Winchendon, Mass.), and the peel was discarded since it contains 2 to 3 times the Ca concentration of subtending flesh (10). Another layer directly beneath the peel was then taken from around the circumference of the apple. This strip of cortex was saved for analysis and will be referred to as "outer cortex tissue". The tissue was composited within

each block and was frozen until mineral analysis was to be performed. Remaining peeled fruit, with stems and seeds removed, were then ground in a food mill. The resulting product was the basis of the second method and will be referred to as "whole fruit tissue". A 200-gram subsample of the ground whole fruit tissue was combined with 300 grams of deionized, distilled water, mixed to a uniform slurry in a Waring blender, and saved for mineral analysis. In the third method of sub-sampling, juice was decanted from the original tubs of chopped whole fruit and saved for analysis. The decanted juice will be referred to as "juice of whole fruit" or simply as "juice".

Once the fruit sub-samples had been taken, outer cortex and whole fruit tissues were analyzed for Ca, Mg, K, P, and N concentrations. Juice analyses were for Ca, Mg, K, and P; N concentrations of juice were too low for measurement by the methods used.

In the outer cortex method all samples were frozen at -30'C for 7 days. Then, 35 grams of frozen tissue were thinly sliced onto wax paper and dried in a forced draft oven at 65'C for 10 days; after 3 to 4 hours, the tissue was turned onto new wax paper to reduce adhesion. After drying, the tissue was chilled five minutes at -30' and ground through a 20 mesh screen of a micro-Wiley mill in a freezer chest at -30'; this procedure maintained dryness of the samples and produced thorough grinding and mixing. This method was described by Weis, et al. (59). A 1.1 gram sample of dried, ground, outer cortex tissue was digested with 3 ml of 70% perchloric acid and 2 to 4 ml of 70% nitric acid in a 110 ml Kjeldahl flask, cooled, and filled to volume with

deionized, distilled water. After appropriate dilution Ca and Mg were analyzed with an atomic absorption spectrophotometer (Instrumentation Laboratories model 551) using an air/acetylene flame. Lanthanum chloride was added to samples to give a concentration of 0.8% La to reduce interferences from phosphates. K concentration was measured by atomic emission using the same spectrophotometer. Sodium chloride was added to samples to a concentration of 0.1% Na to reduce K ionization. An ascorbic acid method for determining phosphorous, described by Watanabe and Olsen (54) was used to measure P in the digested tissue. A Zeiss PMQ II spectrophotometer, set at 880 nm, was used to determine P concentration, using 1 cm cuvettes. A micro-Kjeldahl procedure modified from that of Stubblefield and DeTurk (47) was used to measure N concentration. Due to low fruit N concentration in apple tissue, 0.5 gram, rather than the 0.2 grams of tissue described in the paper, had to be used for analysis. Amounts of reagents, H_2SO_4 and NaOH, were also proportionately increased for the outer cortex tissue N analysis.

Ten ml aliquots of the whole fruit-water slurry were digested in the same manner as the dried outer cortex tissue after overnight predigestion in the Kjeldahl flasks over a steam bath. Analyses for Ca, Mg, K, and P were as for outer cortex tissue. N was analyzed by macro-Kjeldahl method.

Juice, after appropriate dilution and addition of La for Ca and Mg analyses and Na for K analysis, was directly measured using the I L 551 atomic absorption spectrophotometer.

At the onset of commercial harvest (the second week in September) 11 fruit were harvested from each tree. These were approximately 7 cm diameter fruit selected from around the periphery of the trees. Five fruit from each tree (a total of 125 fruit) in a block were placed in a 1 bushel box which was stored in 0'C air. Five more fruit per tree per block were placed in another bushel box and stored in a CA storage (3% O2, 5% CO2, 3'C). All fruit were stored at the Horticulture Research Center in Belchertown, Massachusetts. The last of the 11 fruit taken per tree was assessed for firmness with a Magness-Taylor pressure tester the day after harvest. Results were composited for the 25 fruit per orchard block.

On 04 February, 1980, the air-stored fruit were removed from storage and placed in a 16'C room. The following day ten 7 cm diameter fruit from each orchard block were tested for firmness. Firmness tests were as at harvest except that only 10 fruit per block were tested,and they were tested twice, on opposite sides of the fruit, instead of only once per fruit. On 26 February, after 3 weeks at 16'C, fruit were assessed for breakdown, rot, bitter pit, and scald. Results were recorded as percent fruit affected by each disorder per sample bushel. Since only a very few sampled bushels contained any fruit with bitter pit, it was decided to drop bitter pit evaluation from the experiment. CA-stored fruit were removed from storage 28 May, 1980, and placed in a 24' room. Firmness was measured the following day in the same manner as after air storage. On 26 May, 1 week after fruit were removed from storage, occurrences of breakdown, rot, and scald were assessed as they had been

on air-stored fruit.

Once fruit mineral analyses, firmness tests, and postharvest disorder assessments were completed, means and ranges were determined for all measurements. Correlation coefficients (r) comparing preharvest fruit mineral concentrations to firmness and disorder incidences were determined. A step-wise multiple linear regression program from the SPSS package (23) was used to develop equations relating fruit firmness and postharvest disorder occurrence to preharvest mineral concentrations.

In 1980 the experiment was expanded, and some changes were made. The number of McIntosh blocks sampled was increased to 49. Of these, 48 were made up of pairs of blocks from 24 orchards. From each orchard 1 block of trees on seedling rootstocks and 1 block on Malling 7 (M-7) rootstocks were sampled. The last orchard had only 1 block of trees sampled, and those were on seedling rootstocks. Another change in 1980 was the addition of leaf sampling. During the week of 21 July leaf samples were collected from each orchard block. Four leaves were taken from the periphery of each of the 25 trees in a block. The 100 leaves per block were composited for mineral analysis. Leaves were dried 1 week in a 65' forced draft oven before grinding in a Wiley mill. Dried samples of 200 mg ground leaf were digested and analyzed for Ca, Mg, K, and P in the same manner as the outer cortex tissue had been. Nitrogen concentration was determined by micro-Kjeldahl (47). Fruit samples for mineral analysis were harvested between 19 and 26 August, 1980. Storage samples were picked between 03 and 16 September. Mineral analyses and

storage conditions were as in 1979. Fruit were removed from air storage 26 January, 1981, placed in a 24' room, and firmness was tested the next day. On 03 February, after 7 days at 24', fruit were assessed for breakdown, rot, and scald as in the 1979 season. CA-stored fruit were taken from storage 26 May, 1981, firmness was tested 27 May, and samples were assessed for disorders on 03 June. CA fruit had been kept at 22-24' after removal from storage.

Means and ranges of leaf and fruit mineral concentrations, firmnesses, and storage disorder occurrences were assembled for the 1980-81 season as they had been in 1979-80. Correlation coefficients (r) comparing leaf as well as fruit mineral concentrations to fruit firmness and disorder percentages were determined. To determine if differences in measured mineral concentrations or postharvest fruit conditions existed between seedling and M-7 trees, paired t-tests were performed. Analysis of covariance was also used to determine if there were significant differences in postharvest fruit conditions which could be attributed to rootstock. These analyses included as covariates the measured mineral concentrations in leaves and fruit. This allowed one to see if rootstock related differences in postharvest fruit conditions were related to the covariates, or if some other, undetermined, factor was involved.

The final statistical analyses performed compared the firmnesses and disorder percentages observed in 1980-81 with values predicted using the equations developed in 1979-80 and applied to the 1980 fruit mineral concentrations. Correlation coefficients (r) for these comparisons

showed if the relationships established during the experiment's first year were also valid the second year.

C H A P T E R IV

RESULTS

In order to relate mineral concentrations in fruit to occurrences of fruit disorders after storage, sufficient variations must exist in the occurrences of both element concentration and disorder incidence. Table 1 shows that in 1979 and 1980 fewer than 10% of all fruit showed symptoms of senescent breakdown 1 week after removal from air or CA storage, and even less rot was recorded. Nevertheless, the range of breakdown was considered to be large enough to give an indication of whether mineral nutrition affected incidence of this disorder. However, in the case of rot there may not have been enough variation to establish the effects of mineral nutrition on the disorder. Higher percentages of both breakdown and rot were observed in the fruit from 1980 than those from 1979. There was a wide range of scald incidence among fruit stored in air, but relatively little scald was exhibited on CA fruit. It was therefore anticipated that mineral nutrition would appear to have a greater effect on scald of air-stored fruit than on CA-stored apples. Variations in fruit firmness are shown in Table 2. Firmness values showed little variation from year to year and ranges of values within measurement periods, especially after storage, were small.

Tables 3 and 4 show the variability of the 5 elements measured over the 2 years and 4 methods of analysis; leaf data were not collected in 1979, and juice N was not measurable using the equipment available. For the 4 methods of analysis the relative standard deviation of the element

Table 1. Incidences of fruit disorders after air and CA storage, 1979 and 1980.

Disorder[z]	1979 Mean (%)	1979 Standard deviation	1979 Range (%)	1980 Mean (%)	1980 Standard deviation	1980 Range (%)
			Air storage			
Breakdown	9.4	11.3	0 - 52	3.5	5.3	0 - 24
Rot	6.9	6.4	1 - 19	1.6	2.8	0 - 13
Scald	45.4	25.2	14 - 100	51.8	24.3	12 - 100
			CA storage			
Breakdown	9.4	9.7	0 - 50	9.2	11.3	0 - 51
Rot	4.2	5.8	0 - 31	0.9	1.3	0 - 7
Scald	7.7	11.3	0 - 58	7.6	18.7	0 - 97

[z] Disorders determined after fruit were kept one week at 22-24'C following removal from air or CA storage, except 1979 air-stored fruit which were kept three weeks at 16'C after removal from storage.

Table 2. Fruit firmnesses, in Newtons[z] (N), at harvest, after air storage, and after CA storage, 1979 and 1980.

Time of measurement	Mean (N)	Standard deviation	Range (N)
		1979	
One day after harvest	70.7	4.4	58.3 - 78.3
One day after removal from air storage	42.2	1.7	39.1 - 47.1
One day after removal from CA storage	47.1	2.2	43.2 - 51.6
		1980	
One day after harvest	70.0	4.1	57.8 - 79.2
One day after removal from air storage	42.3	2.2	38.7 - 48.0
One day after removal from CA storage	44.6	3.4	36.5 - 52.0

[z] Newtons = 4.448 x pounds measured using a Magness-Taylor pressure tester.

Table 3. Mineral concentrations in apple leaves in 1980.

Element	Mean (%)	Standard deviation	Range (%)
Ca	0.96	0.14	0.74 - 1.52
Mg	0.30	0.04	0.20 - 0.39
K	1.23	0.20	0.72 - 1.55
P	0.21	0.03	0.14 - 0.28
N	2.16	0.16	1.69 - 2.43

Table 4. Mineral concentrations in apple fruit, measured in outer cortex tissue, whole fruit tissue, and juice of whole fruit, 1979 and 1980.

Element	1979 Mean (ug/g)	1979 Standard deviation	1979 Range (ug/g)	1980 Mean (ug/g)	1980 Standard deviation	1980 Range (ug/g)
			Outer cortex[z]			
Ca	145	22	103 - 183	153	28	101 - 240
Mg	243	15	214 - 278	283	29	241 - 367
K	4909	527	3880 - 6110	5459	553	4200 - 6750
P	360	37	291 - 444	438	44	335 - 551
N	2665	236	2300 - 3300	2227	260	1700 - 2900
			Whole fruit			
Ca	44	7	32 - 66	55	8	42 - 87
Mg	54	4	45 - 62	53	4	40 - 64
K	951	105	660 - 1210	1061	108	820 - 1310
P	96	11	77 - 117	107	17	64 - 152
N	239	60	120 - 350	365	51	210 - 470
			Juice			
Ca	31	4	21 - 40	32	13	16 - 78
Mg	50	5	42 - 63	50	13	25 - 85
K	981	132	690 - 1250	1009	262	540 - 1680
P	49	11	19 - 74	56	18	31 - 102

[z] Outer cortex concentrations are based on dry weight, and whole fruit and juice concentrations are based on fresh weight.

measured exceeded 10% in nearly all cases. Ca, K, and P concentrations were higher as measured by all 3 methods of fruit analysis in 1980 than 1979; Mg in outer cortex was higher in 1980 than in 1979, but was essentially unchanged in whole fruit and juice. From 1979 to 1980 N concentration rose in whole fruit, but dropped in outer cortex tissue.

Having established the ranges of elements, disorders, and fruit firmnesses to be studied, correlation coefficients relating each element to each disorder were determined. Relationships between mineral concentrations and fruit firmnesses also were determined. Results are shown in Tables 5 through 7. In 1979 Ca as measured in outer cortex, whole fruit, or juice related to incidence of breakdown, rot and scald after air storage (Table 5): the greater the Ca concentration, the less of any of the 3 disorders was observed. The only other factors significantly related to a disorder following air storage in 1979 were whole fruit and juice K concentrations, which were positively correlated to scald incidence; that is, the higher the K level, the greater was the incidence of scald. Ca concentration as measured in 1980 fruit again was significantly related to breakdown and scald incidence after air storage. The exception was that juice Ca was correlated to breakdown only at the 7% level. Leaf Ca was not strongly related to fruit disorders except scald after air storage. Very little rot (0.9%) was observed after air storage in 1980, and the only measured element significantly related to rot was leaf Mg. Correlations between elements and disorders were generally weaker after CA storage than after air storage (Table 6). The only fairly consistent relationships were

Table 5. Correlation coefficients (r) between mineral concentrations in leaves, outer cortex tissue, whole fruit, and juice and the incidences of breakdown, rot, and scald of apples after air storage, 1979 and 1980.

	Leaf	Outer cortex		Whole fruit		Juice	
Element	1980	1979	1980	1979	1980	1979	1980
			Breakdown				
Ca	-0.10	-0.67**[z]	-0.49**	-0.58**	-0.48**	-0.53**	-0.28
Mg	-0.24	-0.14	-0.03	0.02	0.01	0.18	0.37*
K	0.27	0.22	0.35*	0.28	0.30	0.29	0.46**
P	-0.12	-0.15	-0.06	-0.11	-0.02	-0.09	0.26
N	0.18	-0.17	-0.14	0.28	0.16	-	-
			Rot				
Ca	-0.02	-0.43*	-0.21	-0.41*	-0.27	-0.43*	-0.14
Mg	0.34*	-0.20	-0.11	-0.31	-0.07	-0.11	0.12
K	-0.26	0.12	0.05	0.14	-0.02	0.06	0.15
P	-0.04	-0.10	-0.13	-0.16	-0.18	-0.18	-0.06
N	0.21	0.07	0.00	0.29	0.13	-	-
			Scald				
Ca	0.29*	-0.61**	-0.30*	-0.38*	-0.33*	-0.42*	-0.35*
Mg	0.18	0.25	0.03	0.22	0.12	0.23	0.39**
K	-0.07	0.33	0.23	0.45**	0.24	0.34*	0.37*
P	-0.22	-0.17	0.14	-0.12	0.12	-0.20	0.22
N	0.31*	-0.01	0.25	0.33	0.31*	-	-

[z] Significant at p=.01 (**) and p=.05 (*) level.

Table 6. Correlation coefficients (r) between mineral concentrations in leaves, outer cortex tissue, whole fruit, and juice and the incidences of breakdown, rot, and scald of apples after CA storage, 1979 and 1980.

	Leaf	Outer cortex		Whole fruit		Juice	
Element	1980	1979	1980	1979	1980	1979	1980
			Breakdown				
Ca	-0.19	-0.50**[z]	-0.42**	-0.34*	-0.45**	-0.39*	-0.37*
Mg	0.29	-0.05	0.18	0.06	-0.00	0.16	0.33*
K	-0.31*	0.13	-0.24	0.21	-0.18	0.16	0.25
P	-0.19	-0.22	-0.03	-0.25	-0.06	-0.22	0.16
N	0.11	-0.16	0.09	0.33	0.23	-	-
			Rot				
Ca	-0.33*	-0.38*	-0.14	-0.34*	-0.24	-0.35*	-0.11
Mg	0.24	-0.27	-0.07	-0.27	-0.07	-0.12	0.12
K	-0.18	0.04	-0.01	0.03	-0.05	-0.02	0.15
P	0.17	0.02	-0.16	-0.03	-0.12	-0.10	0.02
N	-0.07	-0.16	-0.26	0.25	0.02	-	-
			Scald				
Ca	-0.07	-0.39*	-0.07	-0.20	-0.03	-0.27	-0.01
Mg	0.29*	0.12	-0.14	0.24	-0.23	0.23	-0.02
K	-0.21	0.26	0.04	0.33	0.02	0.23	0.05
P	-0.13	-0.04	-0.08	-0.06	-0.10	-0.14	-0.04
N	-0.03	-0.07	-0.17	0.30	-0.10	-	-

[z] Significant at p=.01 (**) and p=.05 (*) level.

Table 7. Correlation coefficients (r) between mineral concentrations in leaves, outer cortex tissue, whole fruit, and juice and fruit firmness at harvest, after air storage, and after CA storage, 1979 and 1980.

	Leaf	Outer cortex		Whole fruit		Juice	
Element	1980	1979	1980	1979	1980	1979	1980
			Harvest				
Ca	-0.05	0.05	0.19	0.05	0.23	0.01	-0.02
Mg	-0.16	-0.08	0.33*[z]	-0.37*	0.38**	0.02	0.27
K	0.20	0.02	0.24	0.04	0.35*	0.17	0.21
P	0.12	-0.02	0.15	0.14	0.34*	0.30	0.23
N	-0.44**	-0.23	0.22	-0.45**	-0.03	-	-
			After air storage				
Ca	-0.23	0.06	0.36*	-0.06	0.41**	-0.05	0.27
Mg	-0.02	-0.09	0.30*	-0.37*	0.28	-0.00	0.15
K	0.13	0.15	0.31*	0.17	0.29*	0.17	0.10
P	-0.02	-0.14	0.10	-0.00	0.07	0.13	0.00
N	-0.31*	-0.21	0.14	-0.19	0.03	-	-
			After CA storage				
Ca	-0.02	-0.06	-0.34*	-0.01	- 0.29*	-0.11	0.29*
Mg	0.01	0.21	-0.04	0.02	-0.06	0.23	-0.35*
K	-0.12	0.12	-0.19	0.15	-0.14	0.34*	-0.29*
P	0.18	0.29	-0.04	0.32	0.04	-0.20	-0.16
N	-0.14	0.09	0.04	-0.15	-0.29*	-	-

[z] Significant at p=.01 (**) and p=.05 (*) level.

between Ca concentration in outer cortex, whole fruit, and juice, and the occurrence of breakdown. There were a few other significant fruit mineral disorder correlations, but these were not consistent from year to year; for example, in 1979 a significant relationship was found linking outer cortex Ca to scald following CA storage of fruit. In 1980 this relationship was weak, not even close to significance at the 5% level even though total scald incidence was about the same for the 2 years (Table 1). Effects of mineral concentration on fruit firmness were highly variable (Table 7). In 1980 leaf N was negatively correlated to fruit firmness at harvest and after air storage. For the other 3 mineral measurement methods, 2 years of analyses were available. In each case where a mineral concentration was significantly correlated to fruit firmness in 1 year, either the correlation was extremely weak (less than 0.18) or was significantly correlated but showed the opposite relationship in the other year.

Having established that there were significant relationships linking mineral nutrition and storage disorders, the next step was to determine whether these differences were related to rootstock. Table 8 shows the means of the measured elements in leaf, outer cortex tissue, whole fruit, and juice of whole fruit for fruit from both seedling and M-7 rootstocks in 24 orchards in 1980. These values were compared using a paired t-test. Each pair consisted of 1 sample from seedling and 1 from M-7 trees in the same grower's orchard. The only significant differences between mineral measurements were for Mg as measured in outer cortex and whole fruit and Ca as measured in juice. Mg

Table 8. Paired t-tests comparing mineral concentrations of leaves and fruit of seedling and M-7 rootstock trees in 24 orchards in 1980.

		Leaf		Outer cortex		Whole fruit		Juice	
Element	Rootstock	Mean (%)	t	Mean (ug/g)	t	Mean (ug/g)	t	Mean (ug/g)	t
Ca	Seedling	0.94	-1.6	158	1.7	56	1.2	35	2.2*[z]
	M-7	0.99		149		54		29	
Mg	Seedling	0.31	1.0	289	3.1**	54	3.0**	51	0.3
	M-7	0.30		277		52		50	
K	Seedling	1.27	1.8	5540	1.3	1070	0.8	1005	-0.3
	M-7	1.20		5420		1060		1020	
P	Seedling	0.20	-1.4	443	1.0	109	1.3	57	0.5
	M-7	0.21		434		105		55	
N	Seedling	2.13	-1.2	2250	0.8	365	-0.3	-	-
	M-7	2.18		2220		365		-	

[z] Significant at p=.01 (**) and p=.05 (*) level.

concentration was higher in outer cortex and whole fruit tissues from seedling than M-7 trees. Juice Ca concentration was higher from seedling than M-7 trees. Differences between percent breakdown found in fruit from seedling and M-7 trees were seen after CA storage as shown in Table 9. There was significantly more breakdown of fruit from M-7 than from seedling trees after CA storage of fruit. This difference was not seen after air storage. Table 9 also shows that significantly more rot was found on air-stored, but not CA-stored, fruit from M-7 trees than on fruit from seedling rootstock trees. No rootstock effect was observed on incidence of scald. Similar analyses comparing rootstock-related firmness differences are also shown. Rootstock differences in fruit firmness were highly significant for air-stored fruit, with fruit from seedling trees being an average of 1.7 Newtons firmer than fruit from M-7 trees. No firmness differences were found at harvest or after CA storage.

These observed differences between the 2 rootstocks, particularly differences in disorder incidence and fruit firmness, may be important when choosing a rootstock for an orchard. However, the concern here is whether or not mineral concentration had the same effect on disorder incidence and fruit firmness regardless of rootstock, not whether there are absolute differences in fruit characteristics based on rootstock.

To determine whether differences in disorders were related to differences between rootstocks other than those differences related to measured minerals, analyses of covariance with the measured elements as covariates were performed. In this procedure the covariate effects

Table 9. Paired t-tests comparing storage disorder incidences and firmness of fruit from seedling and M-7 trees from 24 orchards after air and CA storage in 1980.

		Air storage		CA storage	
Disorder	Rootstock	Mean	t	Mean	t
% Breakdown	Seedling	2.5	-1.6	6.0	-2.6*[z]
	M-7	4.5		11.9	
% Rot	Seedling	0.6	-2.5*	0.6	-1.6
	M-7	2.5		1.2	
% Scald	Seedling	50.2	-1.0	7.1	-0.3
	M-7	54.7		7.5	
Firmness (N)[y]	Seedling	43.1	4.3**	44.9	0.1
	M-7	41.3		44.9	

[z] Significant at p=.01 (**) and p=.05 (*)

[y] Firmness at harvest (N)

Rootstock	Mean	t
Seedling	70.3	0.2
M-7	70.3	

(mineral concentrations) are assessed for their variance along with variance in rootstock. This covariance is then removed from consideration for the analysis of variance which assesses rootstock differences contributing directly to differences in occurrences of fruit disorders (breakdown, rot, and scald) or to differences in fruit firmness. Tables 10 and 11 show the results of such analyses comparing fruit disorders following air and CA storage, respectively. Significant F values for the covariates indicate that the covariates were related to the disorder. A significant F value for the rootstock indicates that incidence of the disorder was related to rootstock characteristics other than through the rootstock's effects on the covariates. Where the rootstock F was significant, further attempts to relate mineral nutrition to fruit storage disorders would require that separate relationships be developed for fruit from trees on seedling or M-7 rootstocks. Using different equations for each rootstock is not commercially feasible. Therefore, analyses which showed significant rootstock effects were not used for later development of disorder prediction equations. Analyses which did not show significant covariate effects were not studied further as it was already established that the covariates were not related significantly to the disorder. For example, since there was not a significant covariate effect of any of the 4 methods of mineral measurement on occurrence of rot after air storage, no further attempt was made to relate the rot to mineral nutrition. In the case of breakdown following air storage, the rootstock did not show an effect, and the covariate effect was highly significant for outer

Table 10. Analysis of covariance for post-air storage disorders for seedling vs M-7 rootstock in 1980.

Source	df	F(Breakdown)	F(Rot)	F(Scald)
	Using leaf Ca, Mg, K, P, and N as covariates:			
Covariates	5	2.84*[z]	1.94	2.44
Rootstock	1	5.67*	5.69*	2.24
Error	38			
	Using outer cortex Ca, Mg, K, P, and N as covariates:			
Covariates	5	4.77**	0.75	3.57**
Rootstock	1	1.02	3.56	0.19
Error	41			
	Using whole fruit Ca, Mg, K, P, and N as covariates:			
Covariates	5	5.55**	1.18	2.78*
Rootstock	1	2.00	5.08*	0.61
Error	42			
	Using juice Ca, Mg, K, and P as covariates:			
Covariates	4	3.91**	1.14	3.20*
Rootstock	1	0.73	4.28*	0.15
Error	43			

[z] Significant at p=.01 (**) and p=.05 (*) level.

Table 11. Analysis of covariance for post-CA storage disorders for seedling vs M-7 rootstocks in 1980.

Source	df	F(Breakdown)	F(Rot)	F(Scald)
	Using leaf Ca, Mg, K, P, and N as covariates:			
Covariates	5	1.78	2.52*[z]	0.83
Rootstock	1	4.81*	1.33	0.00
Error	38			
	Using outer cortex Ca, Mg, K, P, and N as covariates:			
Covariates	5	4.72**	0.77	0.34
Rootstock	1	2.27	1.37	0.08
Error	41			
	Using whole fruit Ca, Mg, K, P, and N as covariates:			
Covariates	5	3.67**	0.59	0.73
Rootstock	1	3.79	1.77	0.24
Error	42			
	Using juice Ca, Mg, K, and P as covariates:			
Covariates	4	2.54	0.47	0.37
Rootstock	1	2.23	1.39	0.07
Error	43			

[z] Significant at p=.01 (**) and p=.05 (*) level.

cortex,whole fruit, and juice, so mineral concentrations measured by these 3 methods were used to try to predict incidence of breakdown following air storage. Scald following air storage was also related to mineral concentration of outer cortex, whole fruit, and juice. Results shown in Table 11 indicate that measured minerals were not as strongly related to storage disorders following CA storage as they were to storage disorders following air storage. However, minerals measured in the outer cortex and whole fruit did show a significant effect on breakdown. It was decided to include juice measurements in equations for predicting breakdown after CA storage since there was significance at the 5.3% level, and juice minerals were significantly related to breakdown following air storage. No mineral effects were observed on rot or scald following CA storage.

Results of analyses similar to those for storage disorders performed to determine if there were rootstock-related firmness differences between fruit and if the covariates were significant are shown in Table 12. There was a consistent significant or highly significant rootstock effect on fruit firmness following air storage. No further investigation of fruit firmness after air storage was made as separate equations would be required for each rootstock. Because only whole fruit mineral measurements were consistently related to fruit firmness, it was decided not to pursue relationships linking mineral nutrition to fruit firmness. Also, since leaf analyses generally showed rather weak relationships to disorders, no further investigation of their relationships to disorders seemed warranted.

Table 12. Analysis of covariance for fruit firmness differences between seedling and M-7 rootstocks in 1980.

Source	df	F At Harvest	F After Air Storage	F After CA Storage
	Using leaf Ca, Mg, K, P, and N as covariates:			
Covariates	5	2.51*[z]	0.81	0.95
Rootstock	1	1.55	6.94*	0.23
Error	38			
	Using outer cortex Ca, Mg, K, P, and N as covariates:			
Covariates	5	2.36	2.93*	1.40
Rootstock	1	1.28	6.81*	0.24
Error	41			
	Using whole fruit Ca, Mg, K, P, and N as covariates:			
Covariates	5	2.73*	3.69**	2.26
Rootstock	1	1.23	9.78**	0.29
Error	42			
	Using juice Ca, Mg, K, and P as covariates:			
Covariates	4	1.09	1.98	2.37
Rootstock	1	0.31	7.55**	0.44
Error	43			

[z] Significant at p=.01 (**) and p=.05 (*) level.

To summarize the decisions based on results of the analyses of covariance, significant relationships were found connecting fruit mineral concentrations to breakdown following air and CA storage and to scald following air storage. These relations held for measurements of outer cortex tissue, whole fruit, and juice. Therefore, the decision was made to attempt only to predict breakdown following air and CA storage and scald following air storage. Mineral concentrations of outer cortex, whole fruit, and juice were the independent variables. Leaf analyses were not used because the weakness of their correlations with disorders and firmnesses did not offer much hope for success in predicting the disorders and firmnesses. Rot following air or CA storage and scald following CA storage were not strongly related to measured elements so no attempt was made to predict these disorders using the fruit analyses.

The first equations developed were for breakdown following air storage in 1979. Equations developed using step-wise multiple linear regression analysis are shown in Table 13. The coefficient of multiple determination (R^2) is shown in Table 13. This tells the percent variation in breakdown of fruit after air storage which is accounted for by the elements in the equations. For each of the 3 fruit areas analyzed, Ca was the most closely correlated to breakdown. The other elements added 5%, 11%, and 11%, respectively, to the accuracies of the outer cortex, whole fruit, and juice equations. Outer cortex measurements explained the highest percent of breakdown variation; juice measurements explained the least, whether Ca alone was in the equation

Table 13. Breakdown after air storage as a function of fruit mineral concentrations in outer cortex tissue, whole fruit tissue, and juice of whole fruit in 1979.

	R^2
Using outer cortex mineral concentrations:	
% Breakdown = 60 - (0.35 x Ca^z)	0.45
% Breakdown = 107 - (0.37 x Ca) - (0.22 x Mg) + (0.052 x P) - (0.0025 x N) - (0.00078 x K)	0.50
Using whole fruit mineral concentrations:	
% Breakdown = 49 - (0.92 x Ca)	0.33
% Breakdown = 48 - (0.87 x Ca) + (0.048 x N) - (0.27 x P) + (0.0075 x K) + (0.12 x Mg)	0.44
Using juice mineral concentrations:	
% Breakdown = 52 - (1.4 x Ca)	0.29
% Breakdown = 25 - (1.6 x Ca) - (0.14 x P) + (0.81 x Mg) - (0.00042 x K)	0.40

[z] All element concentrations are in ug/g . Outer cortex concentrations are based on dry weight, and whole fruit and juice concentrations are based on fresh weight.

or if all measured elements were included. Similar analyses comparing mineral concentrations to breakdown of fruit after CA storage are shown in Table 14. As with fruit breakdown following air storage, Ca was the element most closely related to breakdown, but the correlation coefficients were not as high as for the comparison between Ca and breakdown following air storage. Using Ca alone in the equations, outer cortex mineral levels were most closely related to breakdown, followed by juice and whole fruit mineral levels. When the other elements were added, the coefficient of multiple determination (R^2) increased by 4%, 26%, and 14%, respectively, for outer cortex, whole fruit, and juice equations. With all elements in the equations, the whole fruit equation explained the highest percent (38%) of breakdown variability, while outer cortex and juice each explained 29% of breakdown variability. Equations developed relating mineral concentrations to incidence of scald after air storage of fruit are shown in Table 15. Because K was the most important element of those measured in whole fruit in relation to scald, equations were developed for K as well as for Ca alone. Equations with K alone explained 20% of the variability in scald when whole fruit K concentrations were used. With outer cortex or juice K concentration as the independent variable, 11% of scald variability was explained. Using Ca alone as the independent variable in the equation 38%, 18%, and 11% of scald variation was explained by the outer cortex, juice, and whole fruit equations, respectively. Equations including all measured elements in outer cortex explained 64% and in whole fruit explained 48% of scald variability; the equation using juice explained

Table 14. Breakdown after CA storage as a function of fruit mineral concentrations in outer cortex tissue, whole fruit tissue, and juice of whole fruit in 1979.

	R^2
Using outer cortex mineral concentrations:	
% Breakdown = 41 - (0.22 x Ca^z)	0.25
% Breakdown = 55 - (0.23 x Ca) - (0.045 x P) - (0.0017 x K) + (0.037 x Mg) + (0.0014 x N)	0.29
Using whole fruit concentrations:	
% Breakdown = 29 - (0.46 x Ca)	0.12
% Breakdown = 18 - (0.30 x Ca) - (0.39 x P) + (0.062 x N) + (0.023 x K) + (0.12 x Mg)	0.38
Using juice mineral concentrations:	
% Breakdown = 36 - (0.85 x Ca)	0.15
% Breakdown = 22 - (1.1 x Ca) + (0.74 x Mg) - (0.21 x P) - (0.0069 x K)	0.29

[z] All element concentrations are in ug/g . Outer cortex concentrations are based on dry weight, and whole fruit and juice concentrations are based on fresh weight.

Table 15. Scald incidence after air storage as a function of fruit mineral concentration in outer cortex tissue, whole fruit tissue, and juice of whole fruit in 1979.

Using outer cortex mineral concentrations:	R^2
% Scald = 147 - (0.70 x Ca^z)	0.38
% Scald = - 33 + (0.016 x K)	0.11
% Scald = - 89 - (0.59 x Ca) + (0.93 x Mg) - (0.52 x P) + (0.054 x N) + (0.0075 x K)	0.64
Using whole fruit concentrations:	
% Scald = - 58 + (0.11 x K)	0.20
% Scald = 104 - (1.3 x Ca)	0.14
% Scald = - 54 + (0.12 x K) + (0.15 x N) - (0.92 x P) + (1.0 x Mg) - (0.45 x Ca)	0.48
Using juice mineral concentrations:	
% Scald = 120 - (2.4 x Ca)	0.18
% Scald = - 17 + (0.064 x K)	0.11
% Scald = 52 - (2.5 x Ca) + (1.3 x Mg) - (0.72 x P) + (0.039 x K)	0.38

[z] All element concentrations are in ug/g . Outer cortex concentrations are based on dry weight, and whole fruit and juice concentrations are based on fresh weight.

38%.

The equations developed in 1979 and shown in Tables 13, 14, and 15 were applied to the mineral concentrations measured in 1980 to try to predict incidence of fruit breakdown after air and CA storage and scald after air storage. Table 16 contains the results of those predictions. By 03 February, 1981, 1 week after fruit were removed from air storage, 4% of the fruit from the 49 orchard blocks exhibited breakdown. Predictions had ranged from 0% using the whole fruit Ca equation to 8% when juice Ca or juice Ca + Mg + K + P equations were used. When predicted breakdown values were compared with actual breakdown values, correlation coefficients were highly significant in all cases, except when the equation for juice Ca was used and for which the correlation coefficient, 0.28, was significant at the 6% level. Comparisons between predictions using only Ca and those using all measured elements do not show a trend. In the case of equations using outer cortex concentrations, using only Ca resulted in prediction of more breakdown (7%) than the equation using all elements predicted (2%) and the correlation coefficient was higher when only Ca was in the equation. Whole fruit equations predicted more breakdown (3%) but still less than that observed, when all elements were incorporated than when only Ca was used (0%). The correlation coefficient was nearly the same in both cases; 0.48 with Ca alone and 0.47 with all elements in the equation. The 2 equations with juice mineral concentrations used as independent variables and breakdown after air storage as the dependent variable predicted 8% breakdown. The correlation coefficient was higher (0.36)

Table 16. Effectiveness of 1979 equations in predicting incidence of breakdown and scald 1 week after air storage and in predicting incidence of scald one week after air storage in 1980.

Predictions as a function of:	% Predicted	% Actual	Correlation coefficient (r)
	Breakdown after air storage		
Outer cortex Ca	7	4	0.49**[z]
Outer cortex Ca + Mg + K + P + N	2	4	0.41**
Whole fruit Ca	0	4	0.48**
Whole fruit Ca + Mg + K + P + N	3	4	0.47**
Juice Ca	8	4	0.28[y]
Juice Ca + Mg + K + P	8	4	0.36**
	Breakdown after CA storage		
Outer cortex Ca	8	9	0.42**
Outer cortex Ca + Mg + K + P + N	4	9	0.51**
Whole fruit Ca	4	9	0.45**
Whole fruit Ca + Mg + K + P + N	12	9	0.26[x]
Juice Ca	9	9	0.37**
Juice Ca + Mg + K + P	7	9	0.43**
	Scald after air storage		
Outer cortex Ca	40	52	0.30*[w]
Outer cortex K	54	52	0.22
Outer cortex Ca + Mg + K + P + N	16	52	0.21
Whole fruit K	57	52	0.24
Whole fruit Ca	30	52	0.33*
Whole fruit Ca + Mg + K + P + N	62	52	0.35*
Juice Ca	44	52	0.35*
Juice K	47	52	0.37**
Juice Ca + Mg + K + P	40	52	0.45**

z ** Significant at p=.01
y Significant at p=.06
x Significant at p=.08
w * Significant at p=.05

when all elements measured were in the equation than when just Ca was used, where r = 0.28.

On 03 June, 1981 CA-stored fruit which had been removed from storage and kept at 22'C for 1 week were assessed for breakdown incidence. Results were compared with predictions based on equations developed using fruit from the 1979 season. Results are in the middle section of Table 16. Some equations under-predicted and some over-predicted breakdown incidence. In all cases except the equation using all measurements of whole fruit, the correlation coefficients comparing actual to predicted breakdown were highly significant. Significance in the one exceptional case was at 7%. As in the case of breakdown after air storage, no clear patterns emerged from the predictions. The highest correlation coefficient, r = 0.51, was for the equation using all elements in outer cortex. This equation also under-predicted breakdown the most: 4% breakdown was predicted, and 9% was observed.

The third group of data in Table 16 shows success of predicting scald after air storage. Correlation coefficients comparing predicted percent scald to actual percent scald were generally poor for outer cortex and whole fruit equations. Equations with outer cortex K and with all outer cortex elements were not significant at $p = 0.05$. Only the Ca equation for outer cortex tissue showed a significant relationship between predicted and actual scald. The whole-fruit equations were somewhat better. The equation with Ca showed significance at $p = 0.05$; the equation with all elements showed significance at $p = 0.05$. Equations developed using juice mineral

concentrations were best for predicting scald. In all 3 equations there was a significant relationship between predicted and actual scald incidence. Equations with K and with K + Ca + Mg + P showed highly significant correlations. Like the breakdown equations, the scald equations sometimes under-predicted and sometimes over-predicted disorder incidence.

No clear best overall method of fruit analysis was determined from these analyses. Table 17 shows correlation coefficients comparing the 4 methods of measuring each element. Values greater than 0.33 are significant at $p = .05$ in 1979, and values over 0.28 are significant in 1980. All elements are significantly correlated for outer cortex vs whole fruit and whole fruit vs juice in both 1979 and 1980. However, caution should be exercised in converting 1 method to another; a correlation coefficient of 0.80 shows only 64% of variation in 1 factor being explained by the other.

Table 17. Correlation coefficients (r) among 3 sampling methods in 34 orchard blocks in 1979 and 4 sampling methods in 49 orchard blocks in 1980.

	Leaf with			Outer cortex with				Whole fruit with Juice	
	Outer cortex	Whole fruit	Juice	Whole fruit		Juice			
Element	1980	1980	1980	1979	1980	1979	1980	1979	1980
Ca	0.18	0.20	0.07	0.83	0.89	0.67	0.46	0.82	0.59
Mg	0.25	0.23	0.05	0.46	0.70	0.27	0.43	0.38	0.38
K	0.80	0.73	0.40	0.88	0.89	0.76	0.59	0.82	0.58
P	0.29	0.74	0.55	0.69	0.65	0.53	0.50	0.87	0.72
N	0.36	0.44	-	0.46	0.44	-	-	-	-

C H A P T E R V

DISCUSSION

Results of 2 years of study indicate that equations relating pre-harvest mineral concentrations of Ca, Mg, K, P, and N in fruit to breakdown after air or CA storage and scald after air storage in the 1979-80 season accounted for a considerable amount of variation observed in disorders. When these equations were applied to pre-harvest fruit mineral concentrations in 1980 to predict disorders in the 1980-81 storage season, correlation coefficients relating predicted to observed disorder incidence were usually highly significant.

In order to assess the importance of this phenomenon, a close look must be taken at the methods used for developing the equations and the potential uses for the equations.

Because this was a field experiment, spread over a large geographical area, there were a great many variables which could not be taken into account. Fruit samples for analysis were taken as near as possible to 2 weeks before regular harvest commenced, but different growers begin harvest at different stages of fruit maturity. No index of maturity was applied to these samples, although it is known that concentrations of Ca (4) and P (25) in fruit change significantly during August and September. The range of climatic conditions in the orchards sampled may also affect mineral nutrition and nutrient deficiency symptoms. Chang, et al. reported immobilization of Ca in stems of tobacco at high temperatures (8). While such temperature effects have

not been shown in apple, they cannot be ruled out. Orchards in different areas may also be subject to different amounts of rainfall during the critical last weeks of the growing season. Relationships between water and nutrient uptake are well established (13). Effects of climatic differences on nutrient content of leaves and fruit should not necessarily affect relationships between mineral concentration and fruit disorder incidence. There are other factors, though, which may influence disorder incidence. Minerals not measured in this experiment may have effects on disorders. Boron, for example, has sometimes been shown to influence the occurrence of fruit breakdown in McIntosh (17,27). Fruit maturity at the time of harvest also influences disorder incidence (27).

Another area of concern in the development and use of equations to predict storage disorders of fruit is the choice of tissue to be analyzed. This experiment showed that use of leaf mineral analysis was poorer than fruit analysis in predicting post-harvest fruit disorders. Other researchers have had some success comparing leaf Ca to post-harvest fruit disorders (10). Measurements of mineral concentrations of juice of whole fruit were of the water soluble mineral fraction since juice was analyzed for Ca, Mg, and K by simply diluting with water and adding La and Na salts. Himelrick has studied relationships between total and water soluble mineral concentrations in apple fruit (18), and has found strong correlations, particularly for K which is nearly 100% water soluble. The work presented here indicates that juice measurements are not as reliable predictors of post-harvest

disorder occurrence as are outer cortex and whole fruit tissue measurements (Tables 13, 14, and 15). This may be because only the water soluble minerals are being measured, while those minerals insoluble in water may also have important roles in maintaining postharvest quality of fruit.

In order to be considered for commercial use, a sampling method must be easy to perform consistently in addition to having demonstrated valid comparisons of results to potential keeping quality of fruit. Unfortunately, both the whole fruit and outer cortex tissue methods have drawbacks here. When the whole fruit tissue was dried overnight in the 110 ml Kjeldahl flask before digestion over a flame, some tissue stuck to the side of the flask. In one case this dried tissue was not dissolved by the nitric acid early in the digestion, but caused an explosion of the flask when hot perchloric acid came in contact with the dried tissue. Perring (32) also cites such an incident. Consequently, this method is considered unsafe without further modification. No such incident occurred with the outer cortex tissue, since it was dry before it was weighed into the 110 ml Kjeldahl flask and washed down easily. The problem associated with the outer cortex tissue method is that it is difficult to peel the fruit consistently, and many people have difficulty operating the White Mountain Apple Peeler. Both the whole fruit tissue and outer cortex tissue methods are quite time consuming, judged a disadvantage, since information gained would be most useful at harvest, only 2 weeks after the samples would be taken. Another possible sampling method, that of using cortical plugs from fruit, has

been described by Ferguson, et al. (16). For this method 1 cm thick equatorial slices were taken from a fruit, and slices were sub-sampled using a 7 cm cork borer. We are currently evaluating this procedure in comparison with the outer cortex method. Cortical plug and outer cortex analyses have shown similar correlations to breakdown. The advantage of using cortical plugs is that fruit are quickly and consistently sampled. Preliminary results suggest that cortical plug mineral concentrations correspond to post-harvest fruit condition as well as outer cortex or whole fruit tissue mineral concentrations do.

The storage and post-storage treatments of fruit are important factors determining their quality after the period during which they are kept at warm temperatures. It is difficult, if not impossible, to accurately recreate storage conditions from year to year. Thus, it may be difficult to compare results of fruit storage treatments from year to year. In order to predict keeping quality of fruit, it must be assumed that it is possible to monitor storage conditions. Also, it must be understood that the best one can hope for is to predict how well fruit will keep under specified conditions. Presumably, fruit stored for a shorter period will emerge from storage in better condition than fruit stored a longer time, if storage conditions are comparable. Similarly, fruit stored at higher than usual temperatures cannot be expected to fare as well as similar fruit stored under more favorable, cooler, conditions.

In this experiment fruit were removed from air storage 04 February, 1980 and placed in a 16'C room. Disorders were slow to appear. After 1

week 5% of fruit displayed breakdown, this increased to 8% after 2 weeks, and to 9% after 3 weeks. Corresponding rot percentages after 1, 2, and 3 weeks were 2%, 3%, and 7%, respectively. The 1980 air stored fruit removed from storage 26 January, 1981, and placed in a 22-24'C room displayed breakdown on 4% of fruit after 1 week and 12% of fruit after 3 weeks at 22-24'C. The decision was made to base equations on the 3 week post-storage results in 1979-80 and compare predicted values to the 1 week disorder observations in 1980-81. It was assumed that 1 week of 22-24'C was about what fruit might be expected to endure under current storage and marketing conditions. The 3 week disorder incidences were used in 1979-80 because the fruit were held at 16'C, a relatively low and not especially stressful temperature for fruit, and the Q10 for this range should be about 2.5 (40). For the CA part of the project, post-storage fruit treatments were similar for the 2 years.

One expects to find different factors contributing to storage life of fruit kept in air rather than in a controlled atmosphere. The altered atmosphere of a CA storage must affect physiological processes in fruit. It is therefore unlikely that one will find similar equations for post-air and post-CA disorders of fruit compared to pre-harvest mineral concentrations. Comparison of Tables 13 and 14 bears this out. In addition, failure of the CA storage equations to explain as much of the variation in disorders as the air storage equations suggests that there is something affecting CA stored fruit only and is not included in the equations. It may be that CA has suppressed development of senescence more than did cold air, or it may be that this difference

results from another nutrient, such as B, or is related to fruit maturity at the time of fruit harvest and storage.

These influences raise a question: What are the limits of the equations? They are not perfect. At best, 50% of post-storage breakdown variability was described by a developed equation. When the 1979-80 equations were applied in 1980-81, correlation coefficients relating actual to predicted disorder incidences were usually significant. However, the exact amounts of disorders were not correctly predicted (Table 16).

Another limit to the usefulnes of the equations is illustrated in Figure 1. The relationship shown between outer cortex Ca concentration and breakdown after air storage in 1979-80 and 1980-81 does not appear to be linear. Linear regression was judged most practical for development of equations. It was expected that there would be some year to year variation in relationships between mineral concentrations and disorders observed. It is difficult to predict just how these variations might present themselves. It is possible, for example, for fruit P concentrations to be excessive 1 year so higher P concentrations would increase fruit breakdown. The next year P concentrations might be considerably lower. It would then appear that higher P would decrease fruit breakdown. Far more data points are required to establish a curve showing optimum, excessive, and deficient concentrations than are needed to establish a line. Assuming that the range of elements in an area as small as Massachusetts is likely to be primarily in only 1 of the 2 ranges, excessive to optimum and optimum to deficient, a line should be

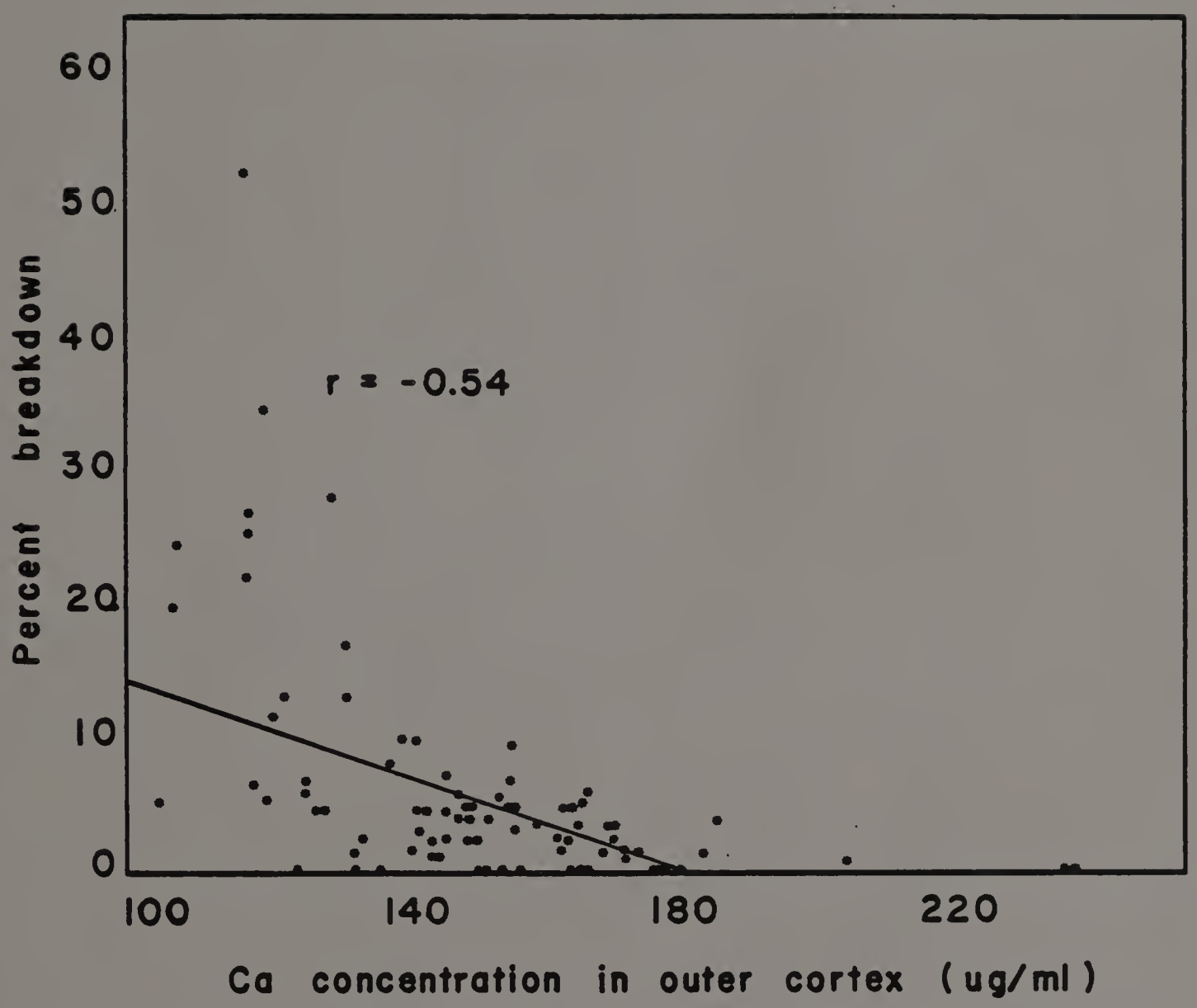

Figure 1. Linear regression comparing outer cortex Ca concentration to breakdown incidence after air storage in fruit from 34 orchard blocks in 1979 and 49 orchard blocks in 1980.

acceptable. Another potential problem with using linear regression is that it is possible to predict less than 0% or more than 100% of a disorder. Very few predictions of less than 0% or more than 100% breakdown have been seen, so it is judged not a serious problem.

Other workers have used ratios of fruit mineral concentrations to predict fruit storage disorders (53). Using this system has advantages and disadvantages. The major advantage is that if it is in fact ratios of element concentrations and not absolute mineral concentrations which affect disorder incidence, this system will incorporate that information. A disadvantage of the ratio system is that it may incorporate the same information more than once. For example, using the Mg/Ca ratio and the K/Ca ratio includes the Ca factor twice. Perhaps the Mg+K/Ca ratio would be more appropriate. Since Mg and K do not perform the same functions, though, probably using the Mg+K/Ca ratio would not be appropriate.

In trying to make decisions concerning what is and is not to be included in predictions, it is important to keep in mind the ultimate goals of the project. The first objective is to devise a system for determining before harvest which blocks of trees have fruit with the potential to emerge from storage in good, marketable condition, and which blocks will produce fruit that are likely to emerge from storage in poor condition. A second objective is to determine (in some cases, reexamine) which elements influence post-storage condition of fruit most strongly.

To achieve the first objective, it is not necessary to predict exactly how many fruit will break down in storage, only to get a rough estimate. If it is predicted that 40% of a lot of fruit will display storage disorders, and 50% of the fruit are later observed to display disorders, the prediction has been a success. Anyone expecting 40% or 50% unsalable fruit from storage would sell those fruit in the fall rather than store them. Likewise, the difference between 3% and 5% breakdown will not cause fruit treatment to be altered. Because Ca appears the critical factor in determining breakdown, the most prevalent disorder except for scald (which is chemically controllable), perhaps the best solution to the commercial problem is to get as much Ca as possible into the fruit. Fruit could be analyzed for Ca concentration 2 weeks before harvest, and if Ca concentration appeared too low, fruit could be dipped in a $CaCl_2$ solution immediately after harvest (1). This post-harvest dip has been recommended often (1,34). A too low Ca concentration might be considered one which predicts over 10% breakdown after 1 week's removal from storage (7). This could be determined by any of the 3 fruit measurement methods, but the outer cortex tissue method seems most appropriate, as mentioned earlier. It must be stressed that this treatment will only affect storage potential. Other factors such as maturity of fruit at harvest and fruit size (27), storage conditions, and length of storage must also be considered.

To achieve the project's second objective, that of determining the different elements' contributions to post-storage fruit disorders, more physiological study is needed. Ca concentration was always negatively

correlated to breakdown, rot, and scald after air or CA storage wherever there was a significant correlation. Mg and N concentrations were positively correlated to these disorders if significantly correlated at all, but seldom showed such correlations. K concentration had mixed effects, and P concentrations never significantly affected disorder incidence. This information may prove useful in supporting explanations of the roles of Ca, Mg, K, P, and N in maintenance of fruit condition in storage.

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APPENDIX A

SUMMARY

In August, 1979, a project was initiated to try to predict postharvest disorders of McIntosh apples grown in Massachusetts. Parameters measured were calcium (Ca), magnesium (Mg), potassium (K), phosphorous (P), and nitrogen (N) concentrations of leaves, whole fruit, and outer cortex tissue, and Ca, Mg, K, and P concentrations of juice of whole fruit. The fruit disorders rated were senescent breakdown (breakdown), rot, and scald, following air and controlled atmosphere (CA) storage of fruit. Relationships between mineral concentrations and fruit firmness at harvest, after air storage, and after CA storage were also determined.

Thirty four orchard blocks were sampled in 1979, and 49 blocks were sampled in 1980. Of the 49 blocks samples in 1980, 48 were in pairs of 2 blocks from each of 24 orchards. One block of trees was on seedling rootstocks, and the other was on Malling-7 (M-7) rootstocks. Leaves were sampled in mid-July 1980, whereas fruit samples were taken 2 weeks before commercial harvest commenced in 1979 and 1980. Fruit firmness was measured 1 day after harvest and 1 day after fruit were removed from air or CA storage. Assessments of fruit disorders were made after fruit were allowed to stand at room temperature for 1 week after air and CA storage. Multiple linear regression equations were developed to compare mineral concentrations of fruit to occurrence of fruit disorders.

No consistent relationships were found linking leaf or fruit mineral concentrations and fruit firmness. Insufficient rot was observed to

warrant statistical comparisons between mineral concentrations and rot incidence. Too little scald observed after CA storage also made comparison of its incidence to mineral concentration impossible. However, enough scald occurred after air storage of fruit to establish a significant negative correlation between fruit Ca concentration and occurrence of scald. This same relationship was established between fruit Ca concentration and breakdown following air and CA storage of fruit. No element other than Ca, at the concentrations observed, was found to be involved in development of breakdown after air or CA storage or scald after air storage, although K concentration was sometimes positively correlated to incidence of scald. Equations developed using 1979 fruit Ca concentrations and fruit Ca + Mg + K + P + N concentrations were useful in predicting breakdown after air and CA storage and scald after air storage in 1980. Rootstock did not affect relationships between mineral concentrations and disorders.

APPENDIX B

Participating Growers

Sincere appreciation is extended to the following apple growers who cooperated in this project:

Howard Atkins	Belchertown
David Bishop	Shelburne
John Blanchard	E. Princeton
Franklyn Carlson	Harvard
David Chandler	Sterling Jct.
Dana and Richard Clark	Ashfield
Thomas Clark	Deerfield
Robert Davis	Bolton
Elmer Fitzgerald, Jr.	Ashby
Elmer Fitzgerald, Sr.	Leominster
Milton Hansen	Granville
William Hermann	Harvard
Melvin Jensen	Granville
Gordon Kimball	Lunenburg
Hamilton Lincoln, Jr.	North Brookfield
Alfred and George Marshall	Fitchburg
Donald May	Groton
Ray Nestrovich	Granville
Edward O'Neill, Sr.	Groton
Marvin and Roger Peck	Shelburne
Donald Priest	Groton
Edward Roberts	Granville
Anthony Rossi	Belchertown
Edward Scott	Ashfield
David Shearer	Colrain
Michael Smith	Shelburne
Dana Sulin	Fitchburg
Robert Tuttle	Warren

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